II. *An Account of ſome new Experiments, relating to the Action of Glaſs Tubes upon Water and Quickſilver.* By James Jurin, M. D. Reg. Soc. & Coll. Med. Lond. Soc.

IN a * Diſcourſe formerly preſented to the *Royal Society*, I maintain'd, that the Suſpenſion of Water in a Capillary Tube was owing to the Attraction of a ſmall annular ſurface on the inſide of the Tube, which touch'd the upper part of the Water. Among the ſeveral Experiments made uſe of to prove this Aſſertion, was that of a Glaſs Funnel of ſeveral Inches Diameter, having its ſmall end drawn out into a very fine Tube, which Funnel being inverted and fill'd with Water, the whole quantity of Water therein contain'd was ſuſtain'd above the Level by the Attraction of that narrow *Annulus* of Glaſs, with which the upper ſurface of the Water was in contact.

Soon after that Diſcourſe was printed, came out a Book publiſh'd by a very Learned and Ingenious Member of this Society, in which that Experiment was accounted for in the following Manner.

If there be a Funnel, as A B C, Fig. 1. *full of Water, and whoſe wide end ſtands in a Veſſel of Water as B C; and the Top of the Funnel A ends in a Capillary Tube open at A, the whole Water will be ſuſtain'd: the Pillar A a by the Attraction of the Circle of Glaſs within the Tube immediately above it; and all the reſt of the Pillars of Water, as F f, D d, E e, G g, &c. in ſome meaſure by the Attraction of the parts of the Glaſs above them, as F,*

* *Philoſ. Tranſact.* N°. 355.

 D, E, G;

D, E, G: And hat the ſmall Pillars or Threads of Water D d, and E e, do not ſlide down to F f, and G g, and ſo go quite down, ſeems to be owing to their Coheſion with the Pillar A a, which is ſuſtain'd by the Capillary Tube A: For if you break off the ſaid Tube at D E, the whole Water will preſently ſink down.

As this Solution was very different from what I had before given, and the Reputation of that Gentleman, whoſe great Knowledge in Experimental Philoſophy is generally known, was ſufficient to give weight to any of his Opinions, I thought my ſelf under an Obligation to examine his account of the Experiment, in order either to demonſtrate its inſufficiency, or to retract my own Solution. Accordingly at the next meeting of the Society, I produced the following Experiment.

The Funnel, A F G B C, *Fig* 2. whoſe lower part B C F G, was Cylindrical to a conſiderable height, and whoſe top was drawn out into a fine Tube at A, being fill'd with Water to the height B F, ſo that the ſurface of the Water F G, did not reach to the arched part of the Funnel, I touch'd the end A with a wetted Finger, whereby a ſmall quantity of Water being inſinuated into the Capillary Tube at A, the Water contain'd in the Funnel was ſuſpended above the Level of the Water in the Ciſtern D E, as in the former Experiment.

In this Experiment it is manifeſt, that the little Columns, into which we may ſuppoſe the Cylinder of Water, F G B C, to be divided, are no way ſuſtain'd by the Attraction of the arched part of the Glaſs above them, ſince they have no contact with it. Nor is there any ſuch middle Pillar of Water, which, by its contact with the Tube at top is both ſuſtain'd it ſelf, and helps to ſupport the Pillars about it. Upon the

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ſuppoſition of which two Particulars that Gentleman's Solution was founded.

This Experiment may be thus accounted for. The Cylinder of Water F G B C, by its weight balances a part of the preſſure of the Atmoſphere, which is incumbent on the Water in the Ciſtern, and endeavours to force that Cylinder upwards. The reſt of that preſſure is balanced by the Spring of the Air, A F G, which is includ d between the Cylinder of Water F G B C, and the little Column of Water in the Capillary A. But, as this Air by its Spring preſſes equally every way, it muſt balance as much of the preſſure of the Atmoſphere upon the little Column of Water at A, as it does of that upon the Water in the Ciſtern. The remainder of the preſſure of the Atmoſphere upon the Column of Water at A is ſuſtain'd by the force with which that Column adheres to the Capillary Tube, which therefore does exactly balance the weight of the Cylinder of Water F G B C, and is the real, though not the immediate, cauſe of its Suſpenſion.

The experiment ſucceeds in the ſame manner when a Column of Quickſilver is raiſed into the Funnel, inſtead of the Column of Water F G B C, the top of the Tube being touch'd with a wet Finger as before. But then the height of the Quickſilver in the Funnel muſt be as much leſs than that of the Water, as its Specifick Gravity is greater.

I proceed now to acquit my ſelf of a Promiſe I made in the Diſcourſe abovemention'd, of examining whether the Experiments therein contain'd would ſucceed *in Vacuo*; and whether Water could be ſuſpended in a wide Tube by means of a Capillary at Top, at a greater height, than what it can be rais'd to by the Preſſure of the Atmoſphere.

In order to this, I boil'd ſome Water, and afterwards purged it of its Air by means of the Air-pump; which being done, thoſe Experiments all ſucceeded in the exhauſted Receiver, in the ſame manner as in the open Air.

The 13*th* Experiment in particular was made with a Tube of about 35 Inches in length, and a quarter of an Inch Diameter, the top of it being drawn out into a fine Capillary. Which being fill'd with Water purged of its Air, as before mention'd, the whole quantity continued ſuſpended in the exhauſted Receiver.

This plainly ſhews, that the ſucceſs of that Experiment does not depend upon the Preſſure of the Air, ſince the ſmall quantity of Air left in the Receiver was by no means capable of ſuſtaining the Water at ſo great a height, and conſequently that the height, at which Water may be ſuſpended in this manner, is not limited by that Preſſure.

But here I muſt not omit taking notice of a conſiderable Difficulty, which preſents it ſelf to thoſe who attentively conſider this Experiment. In order to make which the better appear, it will be proper to obſerve what happens, when a ſimple Capillary Tube is fill'd with Water purged of Air, and inclos'd in the exhauſted Receiver.

In this caſe the whole Column of Water contained in the Tube A C B, *Fig.* 3*d.* is ſuſpended by the Attraction of the *Annulus* at the top of the Tube, A. And though that *Annulus* does not immediately act upon any part of the Water, except what is either contiguous to it, or ſo near as to be within the Sphere of its Attraction, which extends but to a very ſmall diſtance; yet it is impoſſible, that any other part of the Water, as for inſtance that at C, ſhould part from the Water above it and ſink down, becauſe its deſcent is oppos'd by

by the attraction of the contiguous *Annulus* at C. For this, being equal to the upper *Annulus* at A, is capable of ſuſtaining a Column of Water of the length A B, and conſequently is more than ſufficient for ſupporting the Column of Water below it, C B. From which it is plain, that no part of the Water contain'd in the Tube can poſſibly deſcend, unleſs the upper part, aſſiſted by the weight of the Water below it, be ſufficient to overcome the Attraction of the *Annulus* of Glaſs at A.

But in ſuch a compound Tube as that made uſe of in our Experiment, *Fig.* 4*th* A C B, the caſe is very different, and it does not eaſily appear, why in a *Vacuum* any part of the Water in the wider part of the Tube, as for Example at C, ſhould not leave that which is above it, and deſcend; ſince the *Annulus* at C is by much too wide to ſuſtain a Column of Water of ſo great a length as C B.

The beſt anſwer I can give to this difficulty is, that the Coheſion between the Water contain'd in the Capillary and that below it, is ſufficient to balance the weight of the Column ſuſpended. But how far this Coheſion may depend upon the Preſſure of a Medium ſubtile enough to penetrate the Receiver, is worthy of Conſideration. For though ſuch a Medium will pervade the Pores of the Water, as well as thoſe of the Glaſs, yet it will act with its intire Preſſure upon all the ſolid Particles, if I may ſo call them, of the ſurface of the Water in the Ciſtern; whereas ſo many of the ſolid Particles of the Water in the Tube, which happen to lie directly under the ſolid Particles of the Water above them, will thereby be ſecur'd from this Preſſure; and conſequently there will be a leſs Preſſure of this Medium upon any ſurface of the Water in the Tube below the Capillary, than upon an equal ſurface of the Water in the Ciſtern. So that the Column of Water ſuſpended

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in the Tube may be ſuſtain'd by the difference between thoſe two Preſſures. This Explication ſeems to be favour'd by the following Experiments, which may all be accounted for in the ſame manner, though I ſhall anon mention another Cauſe, which contributes to the Succeſs of the firſt and ſecond.

The firſt I ſhall mention, is the famous Experiment of the ſuſpenſion of Mercury purged of Air, to the height of 70 or 75 Inches, in the *Torricellian Tube*, in the open Air. To which we may add the ſuſtaining of Mercury likewiſe purged of Air within the exhauſted Receiver, as related by that Learned and Succeſsful Promoter of Natural Knowledge, Monſ. *Papin*, in his *Continuation du Digeſteur*. I forbear to mention the ſuſpenſion of Water purged of Air, in the *Vacuum*, which he deſcribes in the ſame Book; becauſe there is little difference between that Experiment and our own abovementioned, the very top of the arched part of his Tube, which top we may ſuppoſe as ſmall as we pleaſe, ſupplying the place of the fine Capillary at the top of our Tube. But we muſt not omit the Experiments made by the famous Monſ *Huygens*, and deſcribed by him in *Phil. Tranſact.* No. 86. of the cohering of poliſh'd Plates with a conſiderable force in the exhauſted Receiver; as likewiſe of the running of Water and Mercury, when purged of Air, through a Siphon of unequal Legs in the *Vacuum*: All which he accounts for from the ſame Principle, and much in the ſame manner, as we have uſed for explaining the Experiment above.

As to the Exiſtence of ſuch a Medium, I ſhall content my ſelf to refer to what has been ſaid by our *Illuſtrious Preſident* in the Queries at the latter end of the laſt Edition of his *Opticks:* and as I have lately had the Honour to entertain the Society with ſome Experiments upon Quickſilver, which were exactly the reverſe

reverſe of thoſe made by Dr. *Taylor*, the late Mr. *Hawksbee* and my ſelf, upon Water; by which I am now enabled to throw this whole affair into a little Syſtem by it ſelf, I ſhall beg leave to lay it down in the following Propoſitions, the Proof of which is contain'd in the Experiments annext.

PROPOSITION I.

The Particles of Water attract one another.

This, I think, is now univerſally acknowledged, and therefore needs no Demonſtration; the Sphericity of the drops of Rain, and the running of two drops of Water into one another upon their contact, manifeſtly proving it.

PROPOSITION II.

The Particles of Quickſilver attract one another.

This is likewiſe manifeſt from the Spherical Figure, into which a drop of Mercury forms it ſelf upon a Table; and from two of them immediately running together, as ſoon as they come to touch.

PROPOSITION III.

Water is attracted by Glaſs.

This plainly appears from all the Experiments, that we have ſhewn upon this Subject.

PROPOSITION IV.

Quickſilver is attracted by Glaſs.

Experiment I. If a ſmall Globule of Quickſilver be laid upon a clean Paper, and be touched with a piece of clean Glaſs; upon drawing the Glaſs gently away,

away, the Quickſilver will adhere to it, and be drawn away with it. And if the Glaſs be lifted up from the Paper, the Quickſilver will be taken up by it, in the ſame manner as a piece of Iron is drawn up by the Loadſtone, and will ſtick to the Glaſs by a plain Surface of a conſiderable breadth, in proportion to the bulk of the drop, as manifeſtly appears by an ordinary Microſcope. Then if the Glaſs be held a little obliquely, the drop of Mercury will roll ſlowly upon its Axis along the under ſide of the Glaſs, till it comes to the end, where it will be ſuſpended as before.

Exp. 2*d.* If a pretty large drop of Mercury be laid upon a Paper, and two pieces of Glaſs be made to touch it, one on each ſide; upon drawing the Glaſſes gently from each other, the drop of Mercury will adhere to them both, and will be viſibly drawn out from a globular to an oval Shape; the longer Axis paſſing through the middle of thoſe Surfaces, in which the drop touches the Glaſſes.

PROPOSITION V.

The Particles of Water are more ſtrongly attracted by Glaſs, than by one another.

This manifeſtly appears from the riſing of Water in ſmall Tubes above the Level. For when the Water begins to riſe into a Capillary Tube, all the Particles of Water, which touch the ſmall *Annulus* at the bottom of the Tube, muſt have quitted the contact of the other Water, and have riſen contrary to their Gravity, to come into contact with the Glaſs. After the ſame manner the other Experiments of Dr. *Taylor*, Mr. *Hawksbee* and my ſelf, upon this Subject, are eaſily explicable. For upon a careful Examination, it will be found in

in them all, that ſome parts of the Water quit the contact of the other Water, and join themſelves to the Glaſs.

PROPOSITION VI.

The Particles of Quickſilver are more ſtrongly attracted by one another, than by Glaſs.

Exp I. *Fig.* 5. If a ſmall Tube as A B, open at both ends, be dipt into a Glaſs Veſſel fill'd with Mercury, and be held cloſe to the ſide of the Veſſel, that the riſe of the Mercury within it may appear; the Mercury will partly enter into the Tube, but will ſtand within it at ſome depth, as C E, below the Surface of the Quickſilver in the Veſſel, C D; and this depth will always be reciprocally as the Diameter of the Tube.

In this Experiment a Column of Quickſilver of the height C E endeavours to force the Mercury higher into the Tube; and as Glaſs has been already prov'd to attract Quickſilver, the Attraction of the annular Surface on the inſide of the Tube, which is contiguous to the upper part of the Mercury, will likewiſe conſpire to farther its aſcent. What oppoſes the aſcent of the Quickſilver, is the Power, by which that part of it, which endeavours to riſe into the Glaſs, is drawn back by the Attraction of the other Mercury, with which it is in contact laterally, and this does not only balance the Attraction of the Glaſs, but likewiſe the weight of the Column of Mercury of the height C E, and conſequently this Attraction is conſiderably ſtronger than the Attraction of the Glaſs.

The cauſe therefore that ſuſpends the weight of the Column of Mercury C E, being the difference between the Attraction of the annular Surface of the Tube at E, and that of an equal Surface of the Quickſilver in the Ciſtern, from which the Mercury, that endeavours to

riſe into the Tube, muſt recede, in order to unite it ſelf to ſuch an Annulus of the Glaſs, will always be proportional to that annular Surface, or to the Diameter of the Tube. And ſince the Column ſuſtain'd muſt be proportional to the Cauſe that ſuſpends it, that Column muſt likewiſe be as the Diameter of the Tube. But the Column ſuſpended is as the Square of the Diameter of the Tube and the height C E conjointly; from which it follows, that the height C E muſt be as the Diameter of the Tube reciprocally, as it is found to be by Experiment.

The Experiment of the Aſcent of Water above the Level in a Capillary Tube, is juſt the Reverſe of this.

Exp. II. *Fig.* 6. Quickſilver being poured into the inverted Siphon A C B, one of whoſe Legs A C is narrower than the other C B; the height C E. at which the Mercury ſtands in the wider Leg C B, is greater than the height C D, at which it ſtands in the narrower Leg C A.

On the contrary, Water ſtands higher in the narrower Leg, than in the wider.

Exp. III. *Fig.* 7. A B C D repreſents a rectangular plane of Glaſs, which makes one ſide of a wooden Box. On the inſide of this is another Glaſs plane of the ſame ſize, which at the end A C is preſt cloſe to the former, and opens to a ſmall Angle at the oppoſite end B D. When Mercury is pour'd into this Box to any height as C E, it inſinuates it ſelf between the two Glaſs planes, and riſing to different heighrs between the Glaſſes where the opening is greater or leſs, it forms the common Hyperbola C G F; one of whoſe Aſymptotes E F is the line on which the Surface of the Mercury in the Box touches the inner Glaſs; the other is the line A C, in which the Planes are join'd. This Hyperbola being carefully examined by Mr. *Hawksbee*

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and my ſelf, the Rectangle E H G, whereſoever taken, proved always equal to it ſelf, to as great an accuracy as could be expected, when the Planes were opened to any conſiderable Angle: But when the opening was very ſmall, the inequalities of the Planes, though the beſt I could procure, bearing a greater proportion than before to the diſtance between them, occaſion'd a ſenſible variation. Which, by the way, I take to be the reaſon, why the Ordinates found by the late Mr *Hawksbee*, in examining the Curve produced in a contrary ſituation, upon dipping two Glaſs Planes ſo join'd into Spirit of Wine, do not anſwer to thoſe of the Hyperbola.

Exp. IV. *Fig.* 8. A B is a perpendicular Section through two Glaſs Planes join'd at A, and open'd to a ſmall Angle at B. C repreſents a pretty large drop of Mercury, the larger the better, which, being made to deſcend as far as C, by holding the Planes in an erect poſture, with the end A downwards, retires from the contact of the Planes to D, upon inclining the Planes towards an horizontal Situation; and the diſtance C D becomes greater or leſs, as the Planes are more or leſs inclin'd towards the Horizon.

A drop of any Oily or Watery Liquor moves the contrary way, as has been ſhewn by the late Mr. *Hawksbee.*

Exp. V. *Fig.* 9. A B is a Tube open at both ends, and a Foot or two in length, whoſe lower part is drawn out into a fine Capillary at B. This Tube being fill'd with Mercury, the whole Column of Quickſilver will be ſuſtain'd in it, provided the Capillary Tube at B be ſufficiently ſmall. But if the Mercury in the end B be ſuffer'd to touch any other Mercury it runs all out of the Tube. If, without letting it touch any other Mercury, a ſmall part of the end B be broken off,

the Mercury will run out, till it comes to ſome leſſer height as B C, at which it will again ſtop, the height B C being nearly in a reciprocal proportion to the Diameter of the ſmall end of the Tube.

The Seventh Experiment in *Phil. Tranſ.* N°. 355 is the Reverſe of this.

Exp. VI. *Fig.* 10. Is the ſame in ſubſtance with the former, but made with a large Glaſs Funnel A B, inſtead of a Tube.

The Reverſe of this in Water is the thirteenth Experiment in the ſame Tranſaction.

In all theſe Experiments it is eaſily ſeen, that the Effect is owing to the difference between the two Attractions, by which Mercury tends to Glaſs and to its own body; they being always oppoſed to one another, ſo that a particular Explication is no way neceſſary. But perhaps it may ſave ſome little trouble to the Reader, to remove the following Objection, which will readily occur to him.

In the Experiments brought to demonſtrate the fourth Propoſition, the Globule of Mercury adheres to the Glaſs in a plane Surface, which cannot be done without encreaſing the Surface of the Globule, and conſequently removing ſome of its Particles from the contact of one another. If therefore they tend more ſtrongly to one another than to the Glaſs, why do they not recede from the Glaſs, and aſſume a figure perfectly Spherical, that they may all have the greateſt poſſible contact with each other?

To this we may anſwer, that the Power, by which Mercury is attracted either by Glaſs, or by other Mercury, is proportional to the attracting Surface; and therefore, though, *cæteris paribus*, the tendency of Mercury to Glaſs is not ſo ſtrong as its tendency to other Mercury, yet in this caſe a much greater number of Mer-

Mercurial Particles coming into contact with the Glaſs, than what recede from the contact of one another, it is no wonder, that the Attraction of the Glaſs prevails, and cauſes the Globule to adhere to it. For the number of Mercurial Particles which loſe their contact with the other Mercury, is no more than what makes up the difference of Surface, which ariſes from changing the figure of the Drop: whereas the Particles, which by this means come to adhere to the Glaſs, are all thoſe that conſtitute the plane Surface, in which the Globule touches it.

Which Conſideration ought likewiſe to be apply'd to the Suſpenſion of Quickſilver in Glaſs Tubes, either at extraordinary heights in the open Air, or at leſſer heights in a *Vacuum*, as above mention'd. For the top of the Tube being Spherical, or nearly ſo, it will be found, that the contact of the Mercury with the extremity of the Tube, is to the contact with other Mercury, which would be gain'd by its leaving the Top of the Tube and deſcending a very ſmall ſpace, in a *Ratio* infinitely great; and conſequently that the contact of the Mercury with the top of the Tube is one cauſe of its Suſpenſion.

Coroll 1*ſt*. From this Propoſition it appears, that in a Barometer made with a narrow Tube, the Quickſilver will never ſtand at ſo great a height as in a wider. Which accounts for the *Phænomenon* ſo often mention'd in the Yearly Hiſtory of the Royal Academy of Sciences at *Paris*, by Monſ. *De la Hire*; that in the Barometer, which he conſtantly made uſe of for his annual Obſervations, the Quickſilver did not riſe ſo high, as in another he kept by him, by about three Lines and a half, which is near a third of an Inch our Meaſure: For he tells us, that the Tube of his Barometer is very ſmall. So that there is no need to have recourſe to any

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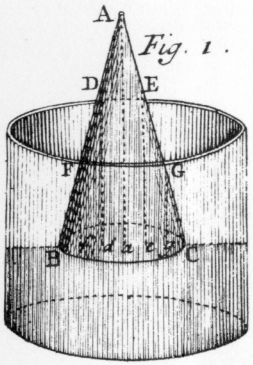
peculiarity either in the Quickſilver or the Glaſs of which that Tube was made; or to an unperceived remnant of Air left in the Tube, from ſome of which cauſes that Effect and ſome others of the ſame kind were imagined to proceed.

Cor. 2*d.* In a Barometer made with a ſmall Tube, the Mercury will riſe and fall irregularly. For, as the height of the Mercury depends partly upon the Diameter of that part of the Tube that touches the upper Surface of the Mercury, it is plain, that the unavoidable inequalities in the Diameter of the Tube will be more conſiderable, in reſpect to the whole Diameter; and conſequently will affect the height of the Mercury more in a ſmall Tube than in a wider. And this I take to be the reaſon, why it is ſo very difficult not to ſay impoſſible, to make two Barometers, which ſhall exactly agree in the height of the Quickſilver in all conſtitutions of the Air, eſpecially if the Tubes be very narrow. This irregularity is ſtill more conſiderable in the Pendent Barometer, in which the Quickſilver moves through a large ſpace, in order to make a ſmall alteration in the length of the Column ſuſpended. The ſame conſideration is eaſily extended to thoſe Levels, that depend upon the riſing of Mercury to the ſame height in the oppoſite Legs of a bent Tube; an Inſtrument of which kind has been lately offer'd for the ſervice of the Publick. And as the effect is juſt contrary in Levels made with Water or Spirit of Wine, due regard ought to be had to this Property in the conſtruction of thoſe Inſtruments, by making the Tubes ſufficiently wide, in order to diminiſh the Error as much as poſſible.



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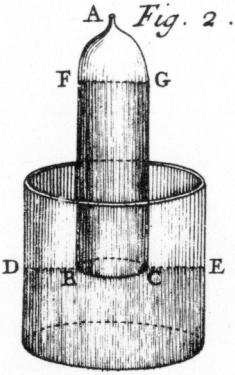

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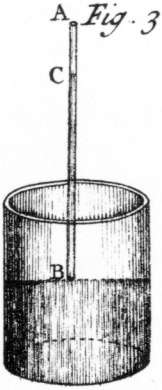

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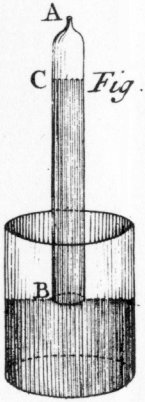

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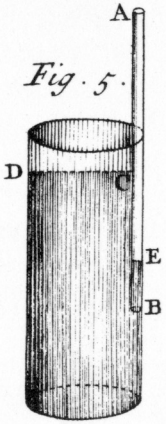

Fig. 5.

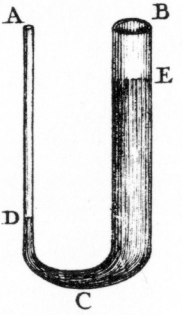

Fig. 6.

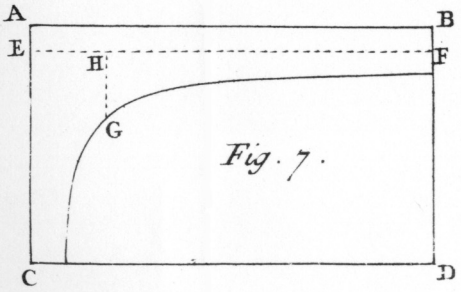

Fig. 7.

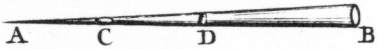

Fig. 8.

Fig. 10.

Fig. 9